PCT

WORLD INTELLECTUAL PROPERTY ORGANIZATION
International Bureau

INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 6 : H04B 15/00, 3/32	A1	(11) International Publication Number: WO 99/26365 (43) International Publication Date: 27 May 1999 (27.05.99)

(21) International Application Number: PCT/SE98/02030

(22) International Filing Date: 11 November 1998 (11.11.98)

(30) Priority Data:
9704256-8 18 November 1997 (18.11.97) SE

(71) Applicant *(for all designated States except US)*: TELIA AB (publ) [SE/SE]; Mårbackagatan 11, S-123 86 Farsta (SE).

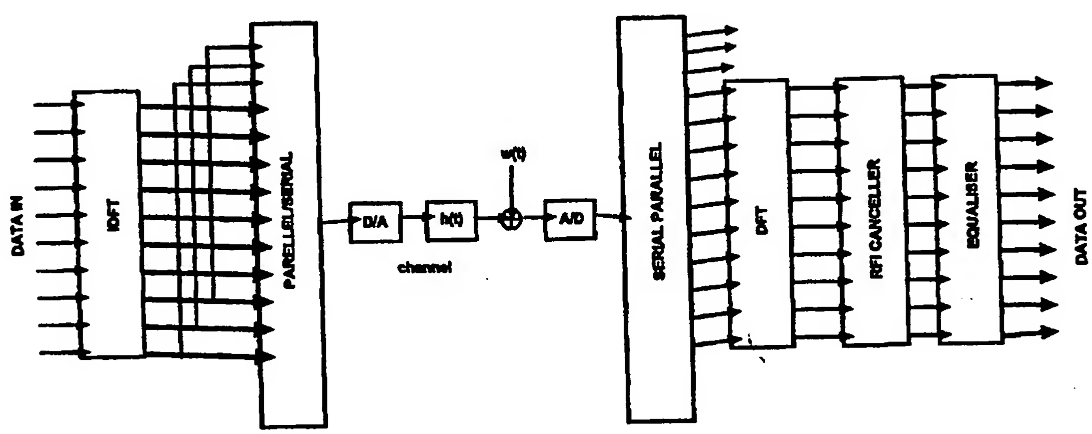
(72) Inventors; and
(75) Inventors/Applicants *(for US only)*: ISAKSSON, Mikael [SE/SE]; Borgmästarevägen 7, S-973 42 Luleå (SE). JOHANSSON, Magnus [SE/SE]; Timmermansgatan 34, S-972 41 Luleå (SE). OLSSON, Lennart [SE/SE]; Majvägen 39, S-973 31 Luleå (SE). STEFANSSON, Tomas [SE/SE]; Lulavan 773, S-961 93 Luleå (SE). ÖHMAN, Hans [SE/SE]; Fältspatstigen 21, S-977 53 Luleå (SE). BAHLENBERG, Gunnar [SE/SE]; Blidvägen 234, S-976 32 Luleå (SE). ISAKSSON, Anders [SE/SE]; Elevvägen 1, S-977 25 Luleå (SE). ÖKVIST, Göran [SE/SE]; Hagaplan 7, S-974 41 Luleå (SE). LJUNGGREN, Lis-Marie [SE/SE]; Praktikantvägen 31, S-977 53 Luleå (SE). BENGTSSON, Daniel [SE/SE]; Forskarvägen 36 A, S-977 53 Luleå (SE). OLOFSSON, Sven-Rune [SE/SE]; Malmuddsvägen 9, S-972 45 Luleå (SE). JOHANSSON, Joachim [SE/SE]; Professorsvägen 11, 5tr, S-977 51 Luleå (SE). BÖRJESSON, Per, Ola [SE/SE]; Mellanbäcksvägen 41, Nygård, S-375 34 Mörrum (SE). GRIP, Niklas [SE/SE]; Kårhusvägen 6:341, S-977 54 Luleå (SE). NILSSON, Richard [SE/SE]; Lingonstigen 30, S-973 32 Luleå (SE). SJÖBERG, Frank [SE/SE]; Forskarvägen 31 A, S-977 53 Luleå (SE). WILSON, Sarah [SE/SE]; Professorsvägen 104 A, S-977 51 Luleå (SE). ÖDLING, Per [SE/SE]; Professorsvägen 109 B, S-977 51 Luleå (SE).

(74) Agent: PRAGSTEN, Rolf; Telia Research AB, Vitsandsgatan 9, S-123 86 Farsta (SE).

(81) Designated States: EE, JP, LT, LV, NO, US, European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE).

Published
With international search report.
Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.

(54) Title: IMPROVEMENT IN, OR RELATING TO, SUBSCRIBER LINE TRANSMISSION SYSTEMS



(57) Abstract

An RFI canceller, for use in a subscriber line system using multi-carrier modulation, measures an RFI disturbance in carriers falling within a band of frequencies causing the RFI. The RFI ingress into carriers outside the band of frequencies is estimated, and an error correcting signal derived from the estimation of the RFI ingress is subtracted form a received signal. The subscriber line system may be a VDSL system and said multi-carrier modulation may be DMT. The RFI canceller includes: a demodulator for demodulating an incoming data stream to provide a first parallel data stream; a parallel to serial convertor for converting the first parallel data stream to a first serial data stream; a digital to analogue convertor for converting said first serial data stream to a first analogue signal; an analogue RFI canceller circuit for combining the analogue signal with an analogue error correcting signal, to produce a second analogue signal; an analogue to a digital convertor for converting the second analogue signal to a second serial data signal; a serial to parallel convertor for converting said second serial data stream to a second parallel data stream; a modulator for modulating the second parallel data stream onto a multiplicity of carriers; and a digital RFI canceller for performing the operations outlined in the first paragraph of this abstract.

FOR THE PURPOSES OF INFORMATION ONLY

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AL	Albania	ES	Spain	LS	Lesotho	SI	Slovenia
AM	Armenia	FI	Finland	LT	Lithuania	SK	Slovakia
AT	Austria	FR	France	LU	Luxembourg	SN	Senegal
AU	Australia	GA	Gabon	LV	Latvia	SZ	Swaziland
AZ	Azerbaijan	GB	United Kingdom	MC	Monaco	TD	Chad
BA	Bosnia and Herzegovina	GE	Georgia	MD	Republic of Moldova	TG	Togo
BB	Barbados	GH	Ghana	MG	Madagascar	TJ	Tajikistan
BE	Belgium	GN	Guinea	MK	The former Yugoslav Republic of Macedonia	TM	Turkmenistan
BF	Burkina Faso	GR	Greece			TR	Turkey
BG	Bulgaria	HU	Hungary	ML	Mali	TT	Trinidad and Tobago
BJ	Benin	IE	Ireland	MN	Mongolia	UA	Ukraine
BR	Brazil	IL	Israel	MR	Mauritania	UG	Uganda
BY	Belarus	IS	Iceland	MW	Malawi	US	United States of America
CA	Canada	IT	Italy	MX	Mexico	UZ	Uzbekistan
CF	Central African Republic	JP	Japan	NE	Niger	VN	Viet Nam
CG	Congo	KE	Kenya	NL	Netherlands	YU	Yugoslavia
CH	Switzerland	KG	Kyrgyzstan	NO	Norway	ZW	Zimbabwe
CI	Côte d'Ivoire	KP	Democratic People's Republic of Korea	NZ	New Zealand		
CM	Cameroon			PL	Poland		
CN	China	KR	Republic of Korea	PT	Portugal		
CU	Cuba	KZ	Kazakstan	RO	Romania		
CZ	Czech Republic	LC	Saint Lucia	RU	Russian Federation		
DE	Germany	LI	Liechtenstein	SD	Sudan		
DK	Denmark	LK	Sri Lanka	SE	Sweden		
EE	Estonia	LR	Liberia	SG	Singapore		

Improvement in, or Relating to, Subscriber Line Transmission Systems

The present invention relates to RFI (Radio Frequency Interference) cancellers for use in subscriber line transmission systems, subscriber line transmission systems incorporating RFI cancellers, receivers, incorporating RFI cancellers, for use with subscriber line transmission systems, and methods of suppressing RFI in telecommunications wire transmission systems employing multi-carrier modulation. The invention has particular application to VDSL systems employing DMT.

The frequency range occupied by VDSL contains several frequency bands, the HAM bands, which are reserved for amateur radio users. VDSL signals on an unshielded twisted wire pair will be disturbed by these radio frequency signals, through common mode (CM) to differential mode (DM) conversion. The commonest example of an RFI signal is the disturbance that VDSL systems receive from a nearby HAM radio transmitter. An analogue RFI canceller, that uses the coupling between CM and DM, can be used to bring the RFI down to a level where it does not saturate the A/D converter in the VDSL receiver. But even if an analog RFI canceller is used, the level of disturbance left can still severely damage the performance of a VDSL system.

The present invention seeks to reduce the RFI in the frequency domain of a DMT based VDSL system after A/D conversion.

Frequency domain Radio Frequency Interference (RFI)-cancellation in the present invention uses a series expansion of the transfer function from the RFI disturbance to the DMT carriers.

Although the present invention is described in relation to VDSL systems employing DMT, it will be apparent to those skilled in the art that the present invention can also be applied to ADSL and related systems, using any multi-carrier modulation method. The necessary modifications of the present invention needed to

apply it to alternative subscriber line transmission systems using multi-carrier modulation, will be immediately apparent to those skilled in the art.

According to a first aspect of the present invention, there is provided a RFI canceller, for use in a subscriber line system using multi-carrier modulation, characterised in that measurement means are provided for measuring a RFI disturbance in carriers falling within a band of frequencies causing said RFI, in that estimation means are provided for estimating RFI ingress into carriers outside said band of frequencies, and in that adder means are provided for subtracting an error correcting signal derived from said estimation means from a received signal.

Preferably, said subscriber line system is a VDSL system and said multi-carrier modulation is DMT.

Said RFI canceller includes:

- a demodulator means for demodulating an incoming data stream to provide a first parallel data stream;
- a parallel to serial convertor for converting said first parallel data stream to a first serial data stream;
- a digital to analogue convertor for converting said first serial data stream to a first analogue signal;
- an analogue RFI canceller circuit for combining said analogue signal with an analogue error correcting signal, to produce a second analogue signal;
- an analogue to digital convertor to convert said second analogue signal to a second serial data signal;

- a serial to parallel convertor for converting said second serial data stream to a second parallel data stream;

- a modulator means for modulating said second parallel data stream onto a multiplicity of carriers; and

- a digital RFI canceller means including said measurement means, said estimation means and said adder means.

Equaliser means may be connected to an output of said digital RFI canceller means.

Said demodulator means may be adapted to perform an inverse discrete Fourier transformation on an incoming digital signal, and said modulator means may be adapted to perform a discrete Fourier transformation on an outgoing digital signal.

Said band of frequencies may be narrow compared to a band of frequencies occupies by said multi-carriers.

Said band of frequencies may correspond to the HAM band.

Said measurement means may operate on at least one carrier within said band of frequencies.

Said estimation means may approximate a transfer function:

$$G_k(f)=\frac{1-e^{j\frac{4\pi fN}{f_s}}}{1-e^{j(2\pi\frac{f}{f_s}-\frac{\pi}{N}k)}}$$

from the RFI disturbance to the DMT carriers, by a linear combination of a

predefined set of basis functions.

Said estimation means may approximate only the denominator of $G_k(f)$, namely:

$$\frac{1}{1-e^{j(\frac{2\pi f}{f_s}-\frac{\pi}{N}k)}}$$

Said measuring means may only perform measurements on carriers having frequencies that are not close to a centre frequency of the RFI disturbance.

Said basis functions may be polynomials.

Said basis functions $\varphi_{k,n}:k\in M\bigcup U$

may bee defined by a linearized model of said RFI disturbance

$$S_k\approx\hat{S}_k=\sum_{n=1}^{L+M}\alpha_n\varphi_{k,n}$$

where α_n are unknown coefficients calculated by using a least-squares fit technique.

Said estimation means may derive said basis functions by means of a Taylor expansion from a linearized model of said RFI disturbance, namely:

$$S_k\approx\hat{S}_k=\sum_{l=0}^{L-1}A_lD^{(l)}{}_k(-f_c)+\sum_{m=0}^{M-1}B_mD^{(m)}{}_k(-f_c)$$

where $\{A_l\}\bigcup\{B_l\}$ is a set of L + M unknown parameter coefficients calculated by said estimation means.

No more than one thousand basis functions may be employed.

No more than ten basis functions may be employed.

According to a second aspect of the present invention, there is provided a subscriber line system using multi-carrier modulation, characterised in that said subscriber line system includes at least one RFI canceller as setforth in any preceding paragraph.

Said subscriber line system may be a VDSL system.

Said subscriber line system may be an ADSL system.

Said multi-carrier modulation may be DMT.

According to a third aspect of the present invention, there is provided a receiver for use with a subscriber line system, as set forth in any preceding paragraph , characterised in that said receiver includes a RFI canceller as set forth in any preceding paragraph.

According to a fourth aspect of the present invention, there is provided a method of reducing RFI in a telecommunications wire transmission system employing multi-carrier modulation characterised by:

- measuring a disturbance signal induced by RFI in carriers falling within a band of frequencies causing said RFI;
- estimating RFI ingress into carriers outside said band of frequencies; and
- subtracting an error correcting signal, derived from an estimation of said RFI ingress, from a received signal.

Said telecommunications wire transmission system may be a VDSL system.

Said telecommunications wire transmission system may be an ADSL system.

Said multi-carrier modulation may be DMT.

Said method may include the steps of:

- demodulating an incoming data stream;
- converting demodulated data to a first serial data stream;
- converting said serial data stream to a first analogue signal;
- combining said first analogue signal with an analogue error correcting signal, to produce a second analogue signal;
- converting said second analogue signal to a second serial data stream;
- converting said second serial data stream to a parallel data stream;
- modulating said parallel data stream onto a multiplicity of carriers; and then
    - measuring a disturbance induced by RFI in carriers falling within a band of frequencies causing said RFI;
    - estimating RFI ingress into carriers outside said band of frequencies; and
    - subtracting an error correcting signal, derived from an

estimation of said RFI ingress, from a received signal.

An outgoing data stream may be equalised.

An inverse discrete Fourier transformation may be performed on an incoming digital signal to demodulate said incoming digital signal, and a discrete Fourier transformation may be performed on an outgoing digital signal to modulate said outgoing signal.

Said band of frequencies may be narrow compared to a band of frequencies occupies by said multi-carriers.

Said narrow band of frequencies may correspond to the HAM band.

Said measurements may be performed on at least one carrier within said band of frequencies.

Said step of estimating may approximate a transfer function:

$$G_k(f)=\frac{1-e^{j\frac{4\pi fN}{f_s}}}{1-e^{j(2\pi\frac{f}{f_s}-\frac{\pi}{N}k)}}$$

from the RFI disturbance to the DMT carriers by a linear combination of a predefined a set of basis functions.

Only the denominator of $G_k(f)$ may be approximated, namely:

$$\frac{1}{1-e^{j(\frac{2\pi f}{f_s}-\frac{\pi}{N}k)}}$$

Measurements may be performed only carriers having frequencies that are not close to a centre frequency of said RFI disturbance signal.

Said basis functions may be polynomials.

Said basis functions

$$\varphi_{k,n}: k \in M \bigcup U$$

may be defined by a linearized model of said RFI disturbance

$$S_k \approx \hat{S}_k = \sum_{n=1}^{L+M} \alpha_n \varphi_{k,n}$$

where α_n are unknown coefficients calculated by using a least-squares fit technique.

Said basis functions may be derived from a Taylor expansion of a linearized model of said RFI disturbance, namely:

$$S_k \approx \hat{S}_k = \sum_{l=0}^{L-1} A_l D^{(l)}{}_k(-\underline{f_c}) + \sum_{m=0}^{M-1} B_m D^{(m)}{}_k(-\underline{f_c})$$

where $\{A_l\} \cup \{B_l\}$ is a set of L + M unknown parameter coefficients and said set of L + M parameters may be calculated.

No more than one thousand basis functions may be employed.

No more than ten basis functions may be employed.

Embodiments of the invention will now be described, by way of example, with reference to the accompanying drawings, in which:

Figure 1 illustrates, in schematic form, the location of apparatus for effecting

RFI suppression according to the present invention, in a DMT transmission system.

Figure 2 is a schematic representation of the operation of the present invention.

Figure 3 is a schematic representation of the RFI disturbance, S_k, on the DMT carriers in a VDSL system.

In order to facilitate an understanding of the present invention a glossary of terms used in the description of the present invention is provided below:

A/D:	Analogue to Digital
ADSL:	Asynchronous Digital Subscriber Line
CM:	Common Mode
D/A:	Digital to Analogue
DFT:	Discrete Fourier Transform
DM:	Differential Mode
DMT:	Discrete Multi Tone
HAM:	Amateur radio
IDFT:	Inverse Discrete Fourier Transform
RFI:	Radio Frequency Interference

VDSL: Very high bit-rate Digital Subscriber Line

As previously explained, the frequency range occupied by VDSL contains several frequency bands, the HAM bands, which are reserved for amateur radio users. This means that VDSL signals, on an unshielded twisted wire pair, can easily be adversely affected by amateur radio frequency transmissions, through common mode (CM) to differential mode (DM) conversion. Although an analogue RFI canceller, using the coupling between CM and DM, can bring the RFI down to a level where it does not saturate the A/D converter in the VDSL receiver, the level of disturbance left can still severely degrade the performance of a VDSL system.

The present invention can be used to reduce the RFI in the frequency domain of a DMT based VDSL system after the A/D conversion.

Operation of the present invention is illustrated in Figure 1. A known technique for analogue RFI cancellelation may be used with the present invention. With such a technique the incoming signal , after it has been subjected to a Inverse Discrete Fourier Transformation (IDFT), parallel to serial conversion and digital to analogue conversion, is combined with an error correcting signal w(t). The present invention is implemented in the block labelled RFI canceller. As illustrated in Figure 1, an incoming data signal is subjected to the following processes:

- IDFT;
- parallel to serial conversion
- D/A conversion;
- analogue RFI cancellation;
- A/D conversion;

- serial to parallel conversion;

- DFT;

- RFI cancellation, according to the present invention; and

- equalisation.

The detailed operation of the RFI cancellation unit, illustrated in Figure 1, is shown in Figure 2. The received signals R_1, R_2, ..., R_{N-1}, are combined with signals $\hat{S}_1$, $\hat{S}_2$, ..., $\hat{S}_{N-1}$, to give output signals Y_1, Y_2, ...Y_{N-1}, where:

$R_1 = X_1.H_1 + S_1 + N_1;$

$R_2 = X_2.H_2 + S_2 + N_2;$

$R_{N-1} = X_{N-1}.H_{N-1} + S_{N-1} + N_{N-1};$

$Y_1 = X_1.H_1 + (S_1 - \hat{S}_1) + N_1;$

$Y_2 = X_2.H_2 + (S_2 - \hat{S}_2) + N_2;$ and

$Y_{N-1} = X_{N-1}.H_{N-1} + (S_{N-1} - \hat{S}_{N-1}) + N_{N-1}.$

A VDSL system cannot transmit any information on carriers in the HAM bands, that is to say, carriers in the HAM band are unmodulated. The method employed by the present invention measures the RFI signal on a number of unmodulated DMT carriers. The RFI disturbance (interference signal) is parametrized. The parameters for this process are estimated using measurements on the unmodulated DMT carriers. Using these parameter estimates, the impact of the RFI signal on all other DMT carriers can be calculated and subtracted from the modulated DMT carriers that convey the received signal. After the subtraction process the interference from RFI on the DMT signal is reduced.

Figure 3 shows the RFI disturbance, on the DMT carriers in a VDSL system. RFI signals are within the HAM band , which is shown in Figure 3 as a shaded area. Typically, a RFI disturbance signal comes from a radio amateur transmission in a HAM-band which coincides with frequencies where unmodulated DMT carriers reside.

The received signal on the modulated DMT carriers can be written as

$$R_m = X_m.H_m + S_m + N_m,\ m \in \{\text{modulated carrier indices}\} = \mathbf{M} \qquad (1)$$

where X_m is the transmitted data, H_m is the channel frequency response, S_m is background noise, and N_m is the RFI signal. On the unmodulated tones the received signal will be

$$R_l = S_l + N_l,\ l \in \{\text{unmodulated carrier indices}\} = \mathbf{U} = \{0,\ 1,\ \ldots,\ N\text{-}1\}\backslash\mathbf{M} = \mathbf{M}^c, \quad (2)$$

where $\mathbf{M}^c$ is the complement set of $\mathbf{M}$.

The impact of the RFI disturbance on DMT carrier k can be expressed as

$$S_k = \int_{-B}^{B} S(f-f_c)G_k(f-f_c)df + \int_{-B}^{B} S(f+f_c)G_k(f+f_c)df, \quad k\in[0,1,\ldots,N-1]=M\bigcup U \quad (3)$$

where $S(f)$ is the unknown Fourier transform of the RFI signal $s(t)$, B is the half the bandwidth of $s(t)$, fc is the centre frequency location of the RFI signal and where:

$$G_k(f) = \frac{1-e^{j\frac{4\pi fN}{f_s}}}{1-e^{j(2\pi\frac{f}{f_s}-\frac{\pi}{N}k)}} \qquad (4)$$

The invention is based on a series expansion of (3). It separates the

dependence between the frequency, f, and the DMT carrier index, k, to obtain a linearized model of the RFI disturbance

$$S_k \approx \hat{S}_k = \sum_{n=1}^{L+M} \alpha_n \varphi_{k,n}, \quad k \in M \bigcup U, \qquad (5)$$

where:

$$\varphi_{k,n} : k \in M \bigcup U$$

is a set of known basis functions and α_n are unknown coefficients calculated as described below.

By measuring the disturbance R_l, $l \in U$ on at least L + M unmodulated DMT carriers as in (2), an estimate of the disturbance on these carriers can be derived. The unknown parameter coefficients, α_n, can then be solved using, for example, a Least-Squares fit. When all $L+M$ parameters α_n are calculated, an estimate of the RFI disturbance on every modulated carrier, $\hat{S}_m$, $m \in M$, can be obtained using (5). These estimates are then subtracted from the received modulated DMT carriers in order to cancel the RFI disturbance

$$Y_m = R_m - \hat{S}_m = X_m H_m + (S_m - \hat{S}_m) + N_m, \quad m \in M \qquad (6)$$

Alternatively, a Taylor series expansion of parts of $G_k(f)$ around the expected centre frequency location, $\pm f_c$, can be used to obtain the linearized model (5). The model will in this case be of the form

$$S_k \approx \hat{S}_k = \sum_{l=0}^{L-1} A_l D^{(l)}{}_k(-f_c) + \sum_{m=0}^{M-1} B_m D^{(m)}{}_k(-f_c), \qquad (7)$$

where $\{A_l\} \bigcup \{B_l\}$ is the set of L + M unknown parameter coefficients that corresponds to α_n in (5) and $D^{(m)}{}_k(f)_c$ is the derivative of the denominator of $G_k(f)$

$$D^{(m)}{}_{k}(f_c)=\frac{d^m}{df^m}\left[\frac{1}{1-e^{j(2\pi\frac{f}{f_s}-\frac{\pi}{N}k}}\right]_{f=f_c}$$

The set $D^{(m)}{}_k(f)_c$ corresponds to the set of basis functions $\{\varphi_{k,n} : k \in M \cup U\}$. The parameters $\{A_i\}$ and $\{B_i\}$ are calculated as above. Then , estimates, $\hat{S}_k$, of the RFI disturbance, are obtained using (7). These estimates are then subtracted from the corresponding modulated DMT tones as showed in (7). The use of a Taylor expansion on $G_k(f)$ gives a fairly simple calculation.

The present invention is useful in any DMT based VDSL system, no matter which duplex method is used.

The technique of the present invention does not require an RFI disturbance signal to be a pure sinusoidal signal at an exactly known frequency . The method for calculating how the disturbance affects the DMT tones is more sophisticated than previous methods because it only assumes that the disturbance has limited bandwidth and that its frequency location is known approximately.

The present invention can be characterised as a technique for frequency domain RFI cancellation in multi-carrier subscriber line systems, such as VDSL. No assumptions are made about the disturber except that it is narrow banded. It uses measurements of one, or many, carriers in each HAM band to estimate the RFI ingress outside the HAM-bands. This estimate is then subtracted from the received signal.

The present invention may also be characterised by the use of the transfer function

$$G_k(f)=\frac{1-e^{j\frac{4\pi N}{f_s}}}{1-e^{j(\frac{2\pi f}{f_s}-\frac{\pi}{N}k)}}$$

from the RFI disturbance to the DMT carriers (sometimes called the Dirichlet kernel) which is approximated by a linear combination of a predefined set of basis functions. Expressions can be simplified by only approximating the denominator part of $G_k(f)$, in other words the expression:

$$\frac{1}{1-e^{j(\frac{2\pi f}{f_s}-\frac{\pi}{N}k)}}$$

The approximation and results can be improved if no measurements are used of the carriers closest to the disturbers centre frequencies.

The basis functions, used in the approximation, may be polynomials.

Furthermore, the number of basis functions used may be limited to 1000, or less. In fact it is possible to use less than 10 basis functions.

CLAIMS

1. A RFI canceller, for use in a subscriber line system using multi-carrier modulation, characterised in that measurement means are provided for measuring a RFI disturbance in carriers falling within a band of frequencies causing said RFI, in that estimation means are provided for estimating RFI ingress into carriers outside said band of frequencies, and in that adder means are provided for subtracting an error correcting signal derived from said estimation means from a received signal.

2. A RFI canceller, as claimed in claim 1, characterised in that said subscriber line system is a VDSL system and said multi-carrier modulation is DMT.

3. A RFI canceller, as claimed in either claim 1, or claim 2, characterised in that said RFI canceller includes:

- a demodulator means for demodulating an incoming data stream to provide a first parallel data stream;
- a parallel to serial convertor for converting said first parallel data stream to a first serial data stream;
- a digital to analogue convertor for converting said first serial data stream to a first analogue signal;
- an analogue RFI canceller circuit for combining said analogue signal with an analogue error correcting signal, to produce a second analogue signal;
- an analogue to digital convertor to convert said second analogue signal to a second serial data signal;

- a serial to parallel convertor for converting said second serial data stream to a second parallel data stream;

- a modulator means for modulating said second parallel data stream onto a multiplicity of carriers; and

- a digital RFI canceller means including said measurement means, said estimation means and said adder means.

4. A RFI canceller, as claimed in claim 3, characterised in that equaliser means are connected to an output of said digital RFI canceller means.

5. A RFI canceller, as claimed in either claim 3, or claim 4, characterised in that said demodulator means is adapted to perform an inverse discrete Fourier transformation on an incoming digital signal, and in that said modulator means is adapted to perform a discrete Fourier transformation on an outgoing digital signal.

6. A RFI canceller, as claimed in any previous claim, characterised in that said band of frequencies is narrow compared to a band of frequencies occupied by said multi-carriers.

7. A RFI canceller, as claimed in claim 6, characterised in that said narrow band of frequencies corresponds to the HAM band.

8. A RFI canceller, as claimed in any previous claim, characterised in that said measurement means operates on at least one carrier within said band of frequencies.

9. A RFI canceller, as claimed in any previous claim, characterised in that said estimation means approximates a transfer function:

$$G_k(f)=\frac{1-e^{j\frac{4\pi fN}{f_s}}}{1-e^{j(2\pi\frac{f}{f_s}-\frac{\pi}{N}k)}}$$

from the RFI disturbance to the DMT carriers, by a linear combination of a predefined set of basis functions.

10. A RFI canceller, as claimed in claim 9, characterised in that said estimation means approximates only the denominator of $G_k(f)$, namely:

$$\frac{1}{1-e^{j(\frac{2\pi f}{f_s}-\frac{\pi}{N}k)}}$$

11. A RFI canceller, as claimed in either claim 9, or claim 10, characterised in that said measuring means only performs measurements on carriers having frequencies that are not close to a centre frequency of the RFI disturbance.

12. A RFI canceller, as claimed in any of claims 9 to 11, characterised in that said basis functions are polynomials.

13. A RFI canceller, as claimed in claim 12, characterised in that said basis functions

$$\varphi_{k,n}: k \in M \bigcup U$$

are defined by a linearized model of said RFI disturbance

$$S_k \approx \hat{S}_k = \sum_{n=1}^{L-M} \alpha_n \varphi_{k,n}$$

where α_n are unknown coefficients calculated by using a least-squares fit technique.

14. A RFI canceller, as claimed in any of claims 9 to claim 12, characterised in that said estimation means derives said basis functions by means of a Taylor expansion from a linearized model of said RFI disturbance, namely:

$$S_k \approx \hat{S}_k = \sum_{l=0}^{L-1} A_l D^{(l)}{}_k(-\underline{f_c}) + \sum_{m=0}^{M-1} B_m D^{(m)}{}_k(-\underline{f_c})$$

where $\{A_l\} \cup \{B_l\}$ is a set of L + M unknown parameter coefficients calculated by said estimation means.

15. A RFI canceller, as claimed in any of claims 9 to 14, characterised in that no more than one thousand basis functions are employed.

16. A RFI canceller, as claimed in claim 15, characterised in that no more than ten basis functions are employed.

17. A subscriber line system using multi-carrier modulation, characterised in that said subscriber line system includes at least one RFI canceller as claimed in any of claims 1 to 16.

18. A subscriber line system, as claimed in claim 17, characterised in that said subscriber line system is a VDSL system.

19. A subscriber line system, as claimed in claim 17, characterised in that said subscriber line system is an ADSL system.

20. A subscriber line system, as claimed in any of claims 17 to 19, characterised in that said multi-carrier modulation is DMT.

21. A receiver for use with a subscriber line system, as claimed in any of claims 17 to 20, characterised in that said receiver includes a RFI canceller as claimed in any of claims 1 to 16.

22. A method of reducing RFI in a telecommunications wire transmission system employing multi-carrier modulation characterised by:

- measuring a disturbance signal induced by RFI in carriers falling within a band of frequencies causing said RFI;
- estimating RFI ingress into carriers outside said band of frequencies; and
- subtracting an error correcting signal, derived from an estimation of said RFI ingress, from a received signal.

23. A method, as claimed in claim 22, characterised by said telecommunications wire transmission system being a VDSL system.

24. A method, as claimed in claim 22, characterised by said telecommunications wire transmission system being an ADSL system.

25. A method, as claimed in any of claims 22 to 24 characterised by said multi-carrier modulation being DMT.

26. A method, as claimed in any of claims 22 to 25, characterised by:

- demodulating an incoming data stream;
- converting demodulated data to a first serial data stream;
- converting said serial data stream to a first analogue signal;
- combining said first analogue signal with an analogue error correcting signal, to produce a second analogue signal;

- converting said second analogue signal to a second serial data stream;
- converting said second serial data stream to a parallel data stream;
- modulating said parallel data stream onto a multiplicity of carriers; and then
  - measuring a disturbance induced by RFI in carriers falling within a band of frequencies causing said RFI;
  - estimating RFI ingress into carriers outside said band of frequencies; and
  - subtracting an error correcting signal, derived from an estimation of said RFI ingress, from a received signal.

27. A method, as claimed in claim 26, characterised by equalising an outgoing data stream.

28. A method, as claimed in either claim 26, or claim 27, characterised by performing an inverse discrete Fourier transformation on an incoming digital signal to demodulate said incoming digital signal, and by performing a discrete Fourier transformation on an outgoing digital signal to modulate said outgoing signal.

29. A method, as claimed in any of claims 22 to 28, characterised by said band of frequencies being narrow compared to a band of frequencies occupied by said multi-carriers.

30. A method, as claimed in claim 29, characterised by said narrow band of frequencies corresponding to the HAM band.

31. A method, as claimed in any of claims 22 to 30, characterised by performing said measurements on at least one carrier within said band of frequencies.

32. A method, as claimed in any of claims 22 to 31, characterised by said step of estimating approximating a transfer function:

$$G_k(f)=\frac{1-e^{j\frac{4\pi fN}{f_s}}}{1-e^{j(2\pi\frac{f}{f_s}-\frac{\pi}{N}k)}}$$

from the RFI disturbance to the DMT carriers by a linear combination of a predefined a set of basis functions.

33. A method, as claimed in claim 32, characterised by approximating only the denominator of $G_k(f)$, namely:

$$\frac{1}{1-e^{j(\frac{2\pi f}{f_s}-\frac{\pi}{N}k)}}$$

34. A method, as claimed in either claim 32, or claim 33, characterised by only performing measurements on carriers having frequencies that are not close to a centre frequency of said RFI disturbance signal.

35. A method, as claimed in any of claims 32 to 34, characterised by said basis functions being polynomials.

36. A method, as claimed in claim 35, characterised by said basis functions

$$\varphi_{k,n}:k\in M\bigcup U$$

being defined by a linearized model of said RFI disturbance

$$S_k \approx \hat{S}_k = \sum_{n=1}^{L \cdot M} \alpha_n \varphi_{k,n}$$

where α_n are unknown coefficients calculated by using a least-squares fit technique.

37. A method, as claimed in any of claims 32 to claim 35, characterised by deriving said basis functions from a Taylor expansion of a linearized model of said RFI disturbance, namely:

$$S_k \approx \hat{S}_k = \sum_{l=0}^{L-1} A_l D^{(l)}{}_k(-\underline{f_c}) + \sum_{m=0}^{M-1} B_m D^{(m)}{}_k(-\underline{f_c})$$

where $\{A_l\} \cup \{B_l\}$ is a set of L + M unknown parameter coefficients and calculating said set of L + M parameters.

38. A method, as claimed in any of claims 32 to 37, characterised by employing no more than one thousand basis functions.

39. A method, as claimed in claim 38, characterised by employing no more than ten basis functions.

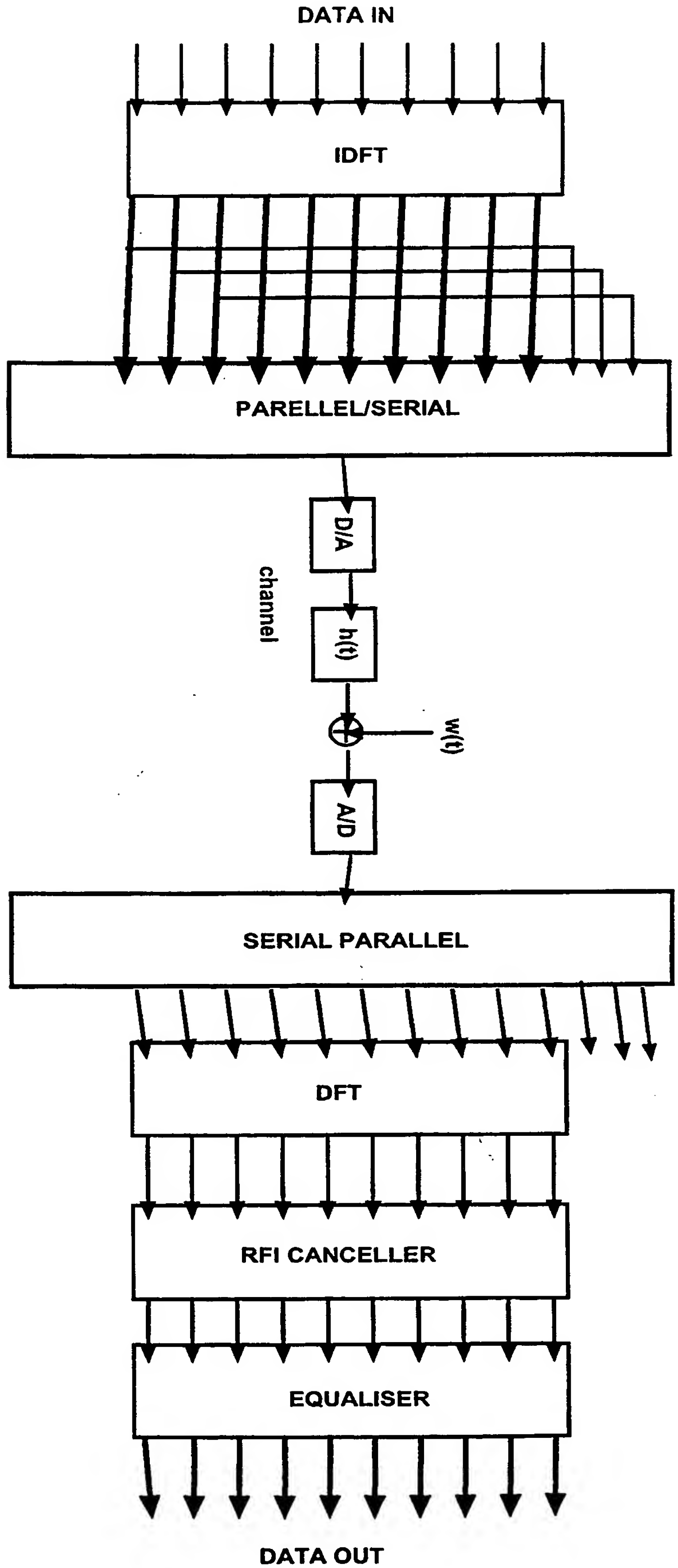

DATA IN
IDFT
PARELLEL/SERIAL
D/A
channel
h(t)
w(t)
A/D
SERIAL PARALLEL
DFT
RFI CANCELLER
EQUALISER
DATA OUT

FIGURE 1

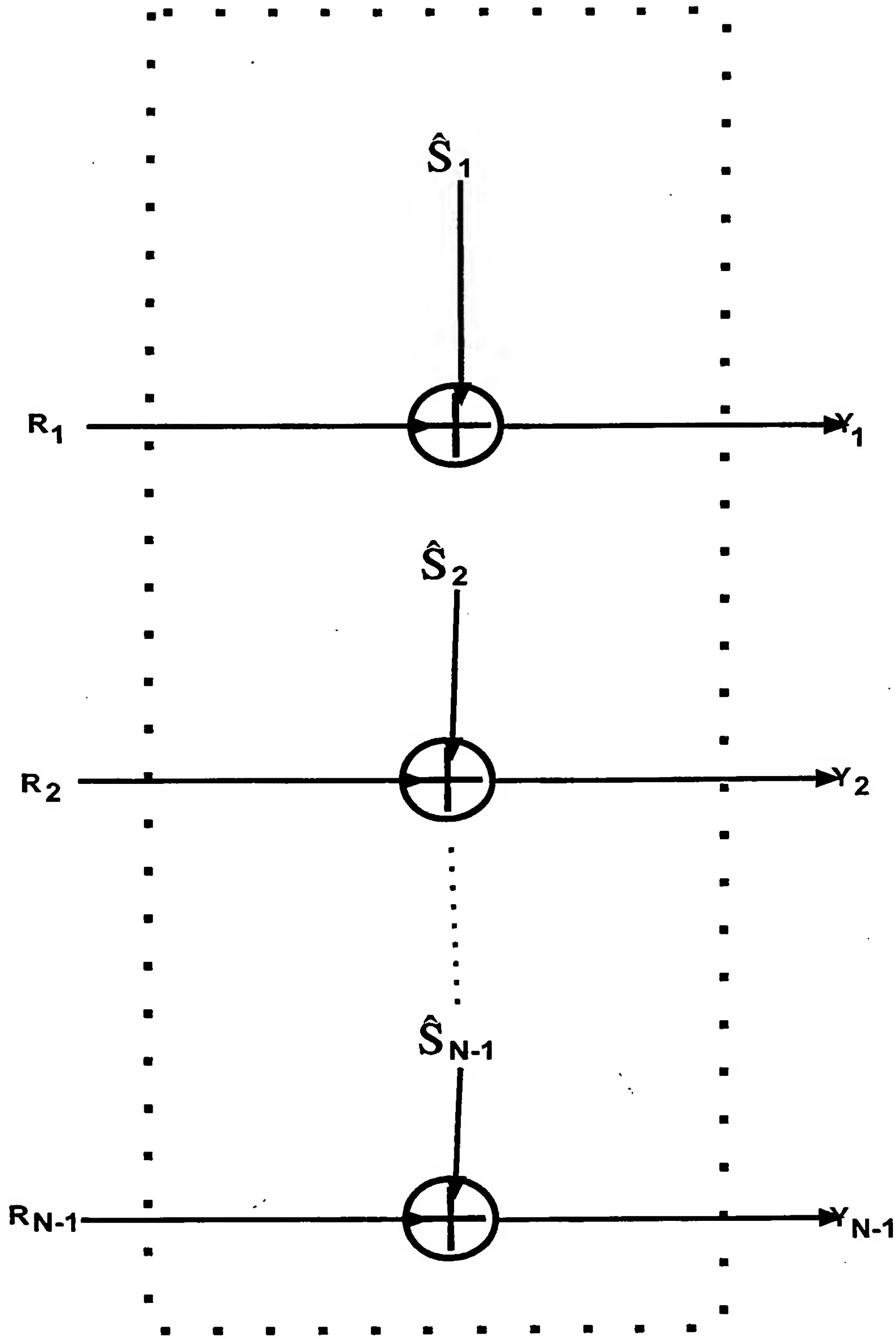


FIGURE 2

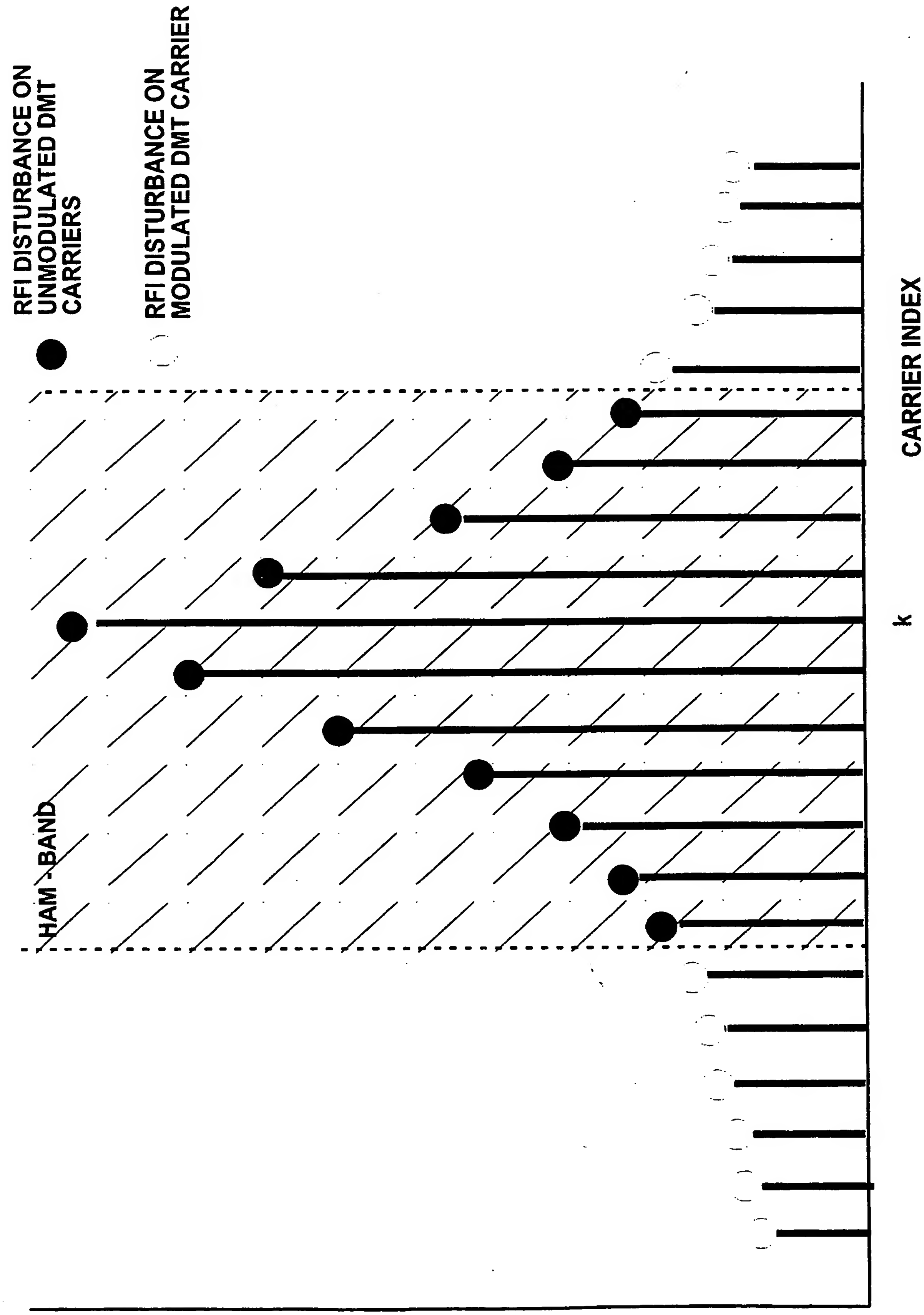

RFI DISTURBANCE ON UNMODULATED DMT CARRIERS
RFI DISTURBANCE ON MODULATED DMT CARRIER
HAM - BAND
k
CARRIER INDEX

FIGURE 3

INTERNATIONAL SEARCH REPORT

International application No.
PCT/SE 98/02030

A. CLASSIFICATION OF SUBJECT MATTER

IPC6: H04B 15/00, H04B 3/32
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC6: H04B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

SE,DK,FI,NO classes as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	IEEE GLOBECOM 1996 COMMUNICATIONS: THE KEY TO GLOBAL ...., Volume 2, November 1996, (New York), John A. C. Bingham, "RFSI Suppression in Multicarrier Transmission Systems", page 1026 - page 1030, see page 1029 --	1-39
A	Broadband Access Networkss page 84-91, Volume, June 1997, (Amsterdam, Netherlands), Schmucking, D. et al, "Proceedings of the European Conference on Networks and Optical Communications 1997" page 90 --	1-39
P,A	EP 0862300 A2 (ORCKIT COMMUNICATIONS LTD.), 12 February 1998 (12.02.98), column 2, line 23 - column 3 --	1-39

[X] Further documents are listed in the continuation of Box C. [X] See patent family annex.

- * Special categories of cited documents:
- "A" document defining the general state of the art which is not considered to be of particular relevance
- "E" erlier document but published on or after the international filing date
- "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
- "O" document referring to an oral disclosure, use, exhibition or other means
- "P" document published prior to the international filing date but later than the priority date claimed
- "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
- "X" document of particular relevance: the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
- "Y" document of particular relevance: the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
- "&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
14 April 1999	19 -04- 1999
Name and mailing address of the ISA/ Swedish Patent Office Box 5055, S-102 42 STOCKHOLM Facsimile No. +46 8 666 02 86	Authorized officer Michel Gascoin Telephone No. +46 8 782 25 00

INTERNATIONAL SEARCH REPORT

International application No.
PCT/SE 98/02030

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	EP 0772309 A2 (NORTHERN TELECOM LIMITED), 7 May 1997 (07.05.97), column 2, line 6 - column 3, line 42 --	1-39
A	EP 0785636 A2 (TEXAS INSTRUMENTS INCORPORATED), 23 July 1997 (23.07.97), abstract --	1-39
A	EP 0773642 A2 (NORTHERN TELECOM LIMITED), 14 May 1997 (14.05.97), abstract --	1-39
A	EP 0773643 A2 (NORTHERN TELECOM LIMITED), 14 May 1997 (14.05.97), abstract -- --------	1-39

INTERNATIONAL SEARCH REPORT
Information on patent family members

02/03/99

International application No.
PCT/SE 98/02030

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
EP 0862300 A2	12/02/98	IL 123096 D	00/00/00
EP 0772309 A2	07/05/97	GB 2307148 A	14/05/97
		GB 9522675 D	00/00/00
		JP 9289476 A	04/11/97
EP 0785636 A2	23/07/97	NONE	
EP 0773642 A2	14/05/97	GB 2307149 A	14/05/97
		GB 9523016 D	00/00/00
		US 5832032 A	03/11/98
EP 0773643 A2	14/05/97	GB 2307150 A	14/05/97
		GB 9523018 D	00/00/00
		JP 9289477 A	04/11/97

Form PCT/ISA/210 (patent family annex) (July 1992)

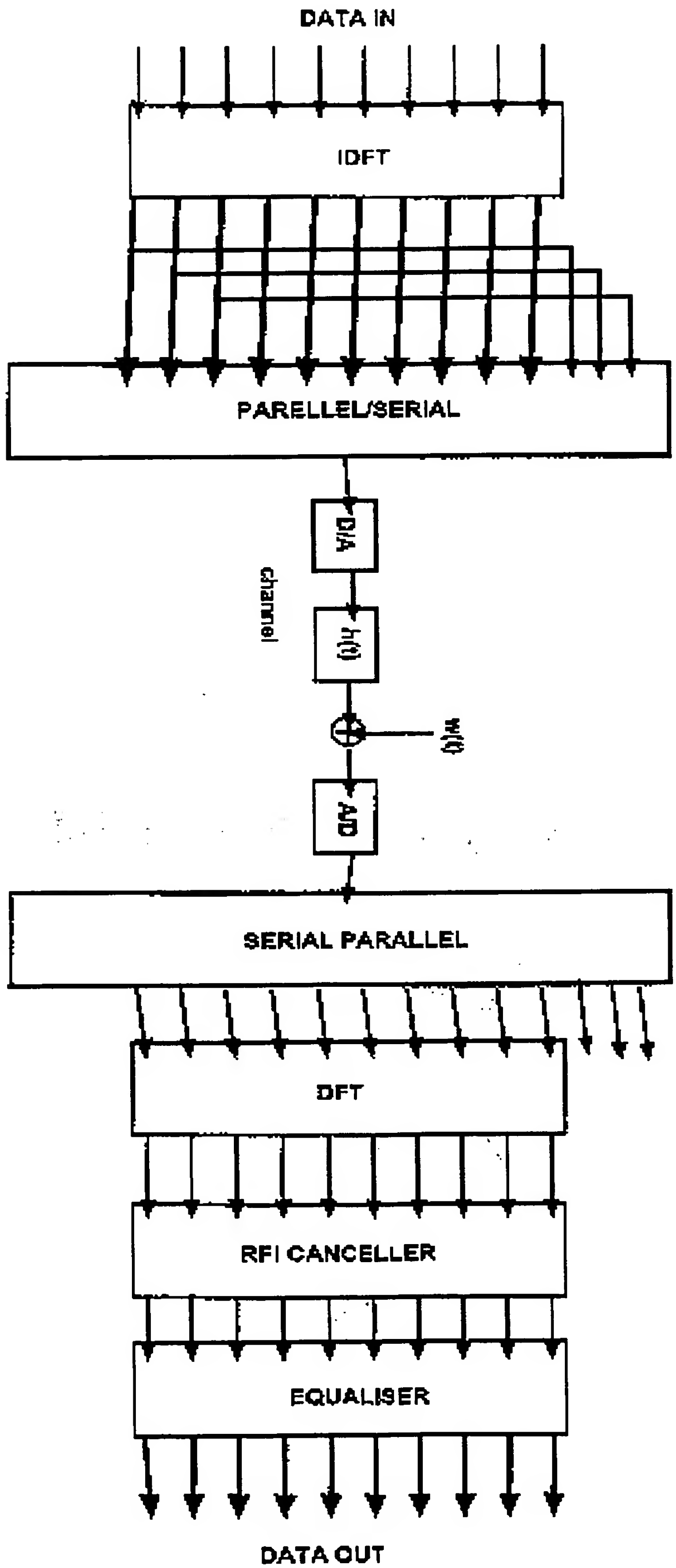

DATA IN
IDFT
PARELLEL/SERIAL
D/A
channel
h(t)
w(t)
A/D
SERIAL PARALLEL
DFT
RFI CANCELLER
EQUALISER
DATA OUT

FIGURE 1

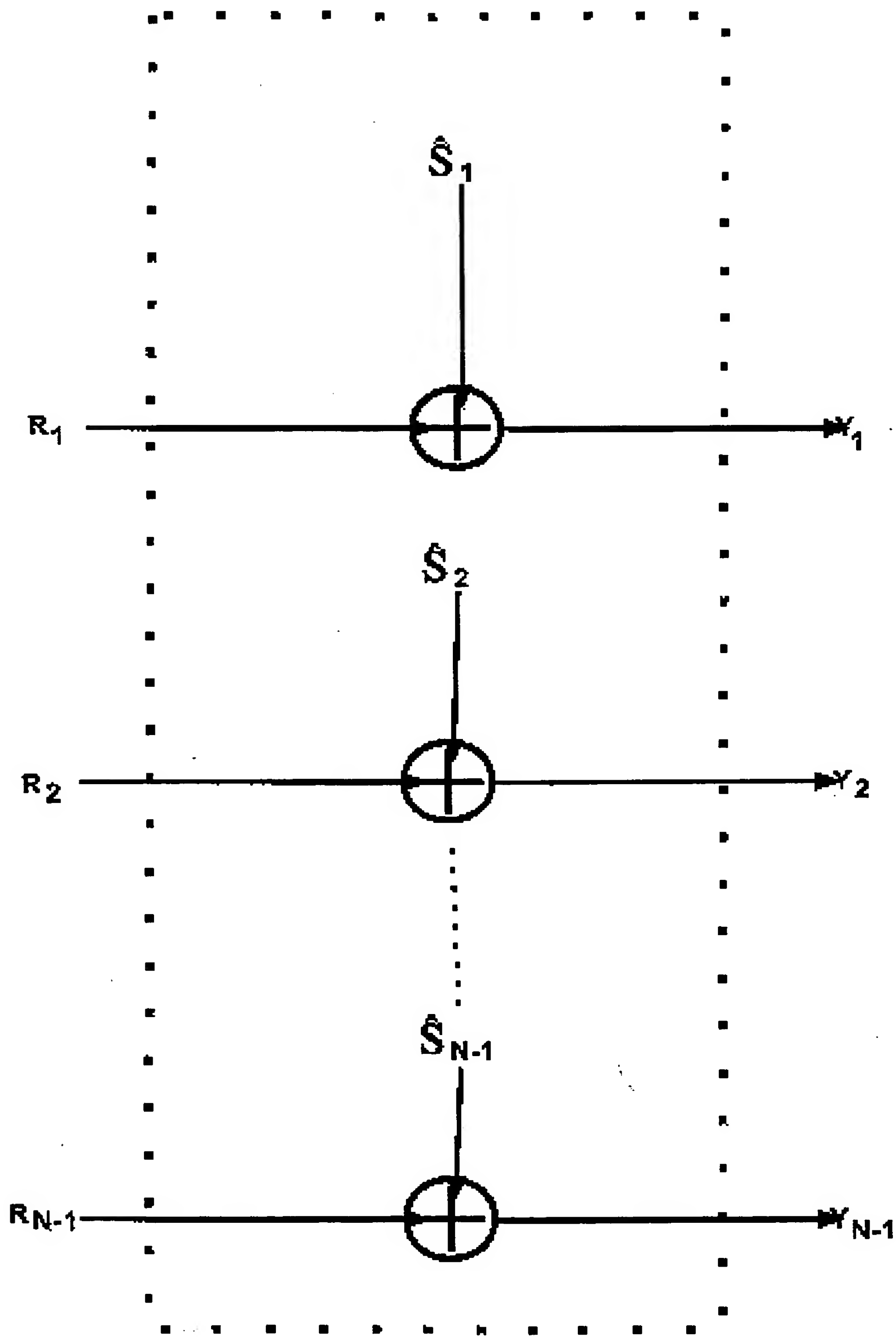


FIGURE 2

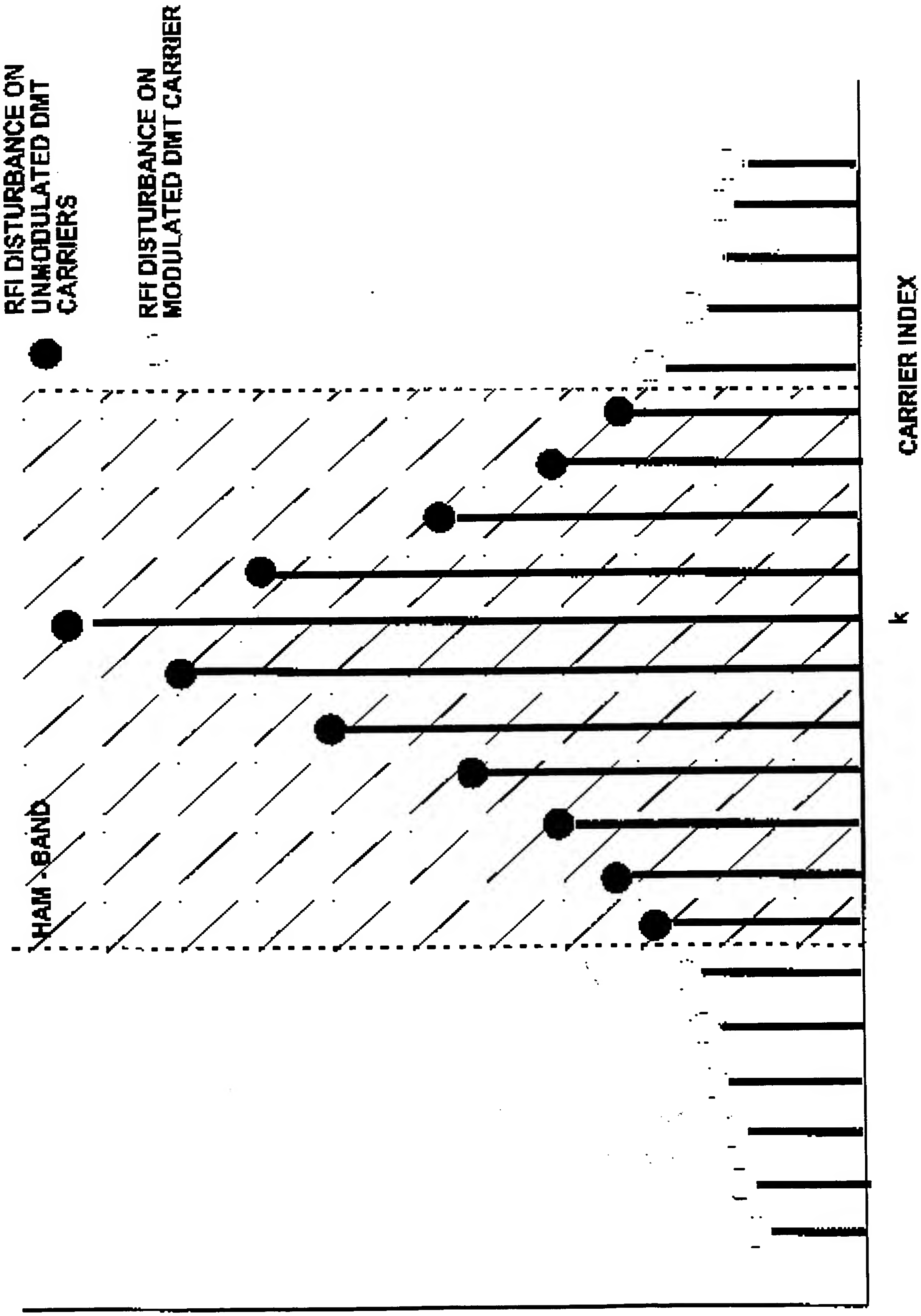

RFI DISTURBANCE ON UNMODULATED DMT CARRIERS
RFI DISTURBANCE ON MODULATED DMT CARRIER
HAM - BAND
k
CARRIER INDEX

FIGURE 3